The Hydrosphere State (Hydros) Satellite Mission: An Earth System Pathfinder for Global Mapping of Soil Moisture and Land Freeze/Thaw

Dara Entekhabi, *Senior Member, IEEE*, Eni G. Njoku, *Fellow, IEEE*, Paul Houser, Michael Spencer, Terence Doiron, Yunjin Kim, *Senior Member, IEEE*, Joel Smith, Ralph Girard, Stephane Belair, Wade Crow, Thomas J. Jackson, *Fellow, IEEE*, Yann H. Kerr, *Senior Member, IEEE*, John S. Kimball, Randy Koster, Kyle C. McDonald, *Senior Member, IEEE*, Peggy E. O'Neill, Terry Pultz, Steve W. Running, Jiancheng Shi, *Senior Member, IEEE*, Eric Wood, and Jakob van Zyl, *Fellow, IEEE*

***Abstract*—The Hydrosphere State Mission (Hydros) is a pathfinder mission in the National Aeronautics and Space Administration (NASA) Earth System Science Pathfinder Program (ESSP). The objective of the mission is to provide exploratory global measurements of the earth's soil moisture at 10-km resolution with two- to three-days revisit and land-surface freeze/thaw conditions at 3-km resolution with one- to two-days revisit. The mission builds on the heritage of ground-based and airborne passive and active low-frequency microwave measurements that have demonstrated and validated the effectiveness of the measurements and associated algorithms for estimating the amount and phase (frozen or thawed) of surface soil moisture. The mission data will enable advances in weather and climate prediction and in mapping processes that link the water, energy, and carbon cycles. The Hydros instrument is a combined radar and radiometer system operating at 1.26 GHz (with VV, HH, and HV polarizations) and 1.41 GHz (with H, V, and U polarizations), respectively. The radar and the radiometer share the aperture of a 6-m antenna with a look–angle of 39° with respect to nadir. The lightweight deployable mesh antenna is rotated at 14.6 rpm to provide a constant look-angle scan across a swath width of 1000 km. The wide swath provides global coverage that meet the revisit requirements. The radiometer measurements allow retrieval of soil moisture in diverse (nonforested) landscapes with a resolution of 40 km. The radar measurements allow the retrieval of soil moisture at relatively high resolution (3 km). The mission includes combined radar/radiometer data products that will use the synergy of the two sensors to deliver enhanced-quality 10-km resolution soil moisture estimates. In this paper, the science requirements and their traceability to the instrument design are outlined. A review of the underlying measurement physics and key instrument performance parameters are also presented.**

***Index Terms*—Land freeze/thaw, microwave remote sensing, satellites, soil moisture.**

Manuscript received November 3, 2003; revised April 6, 2004. This work was supported in part by the National Aeronautics and Space Administration and in part by the author home institutions.

D. Entekhabi is with the Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139 USA (e-mail: darae@mit.edu).

E. G. Njoku, M. Spencer, Y. Kim, J. Smith, K. C. McDonald, and J. van Zyl are with the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109 USA.

P. Houser, T. Doiron, R. Koster, and P. E. O'Neill are with the Hydrologic Sciences Branch, National Aeronautics and Space Administration Goddard Space Flight Center (GSFC), Greenbelt, MD 20771 USA.

R. Girard is with the Canadian Space Agency, Saint-Hubert, J3Y 8Y9 QC, Canada.

S. Belair is with the Meteorological Service of Canada, Dorval, H98 IJ3 QC, Canada.

W. Crow and T. J. Jackson are with the Hydrology and Remote Sensing Laboratory, Agricultural Research Service, U.S. Department of Agriculture, Beltsville, MD 20705 USA.

Y. H. Kerr is with the Centre d'Etudes Spatiales de la Biosphère, 31401 Toulouse Cedex 09, France.

J. S. Kimball and S. W. Running are with the Division of Biological Sciences, University of Montana, Missoula, MT 59860 USA.

T. Pultz is with the Canada Centre for Remote Sensing, Natural Resources Canada, Ottawa, ON K1A 0Y7, Canada.

J . Shi is with the University of California, Santa Barbara, CA 93106 USA.

E. Wood is with Department of Civil and Environmental Engineering, Princeton University, Princeton, NJ 08854 USA.

Digital Object Identifier 10.1109/TGRS.2004.834631

I. Introduction

THE Hydrosphere State (Hydros) Mission will use a combined passive/active low-frequency (L-band) microwave instrument to measure the land hydrosphere state globally from space. Hydros will provide measurements of surface soil moisture (0–5 cm depth) and land freeze/thaw over a wide 1000-km swath with a global revisit of two to three days (one to two days above 50° latitude). Over 70% of the swath the radar resolution is better than 3 km. The radiometer resolution is about 40 km. Measurements from these sensors are combined to produce a global 10-km soil moisture data product.

The radar and the radiometer share the aperture of a large (6 m) but lightweight deployable mesh reflector. The reflector rotates to make conical scans over a wide swath (∼1000 km). In this way. Hydros will produce global mapping with high revisit (see Fig. 1).

The Hydros mission has been selected as a National Aeronautics and Space Administration (NASA) Earth System Science Pathfinder (ESSP). In this paper, the scientific basis and the measurement approach for the Hydros mission are described. In Section II, the scientific motivation for making the measurements is presented. The science and application requirements for measurements are defined, and the underlying physics of the measurements are also reviewed. The measurement requirements and underlying physics are traced to the instrument concept outlined in Section III. In Section IV, the retrieval algorithms and data products are reviewed. The status of the Hydros mission and time-line for implementation are presented in the concluding Section V.

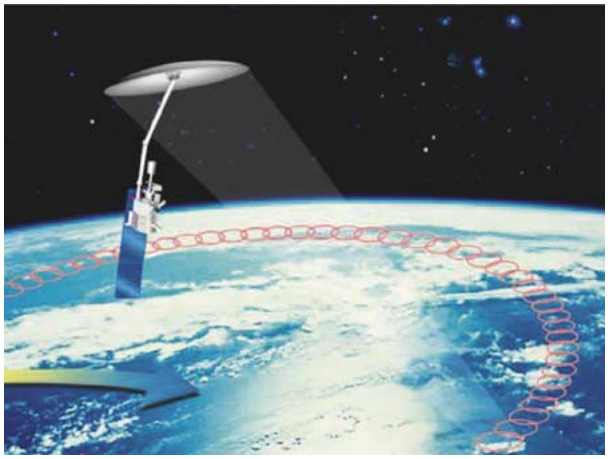

Fig. 1. Hydros mission.

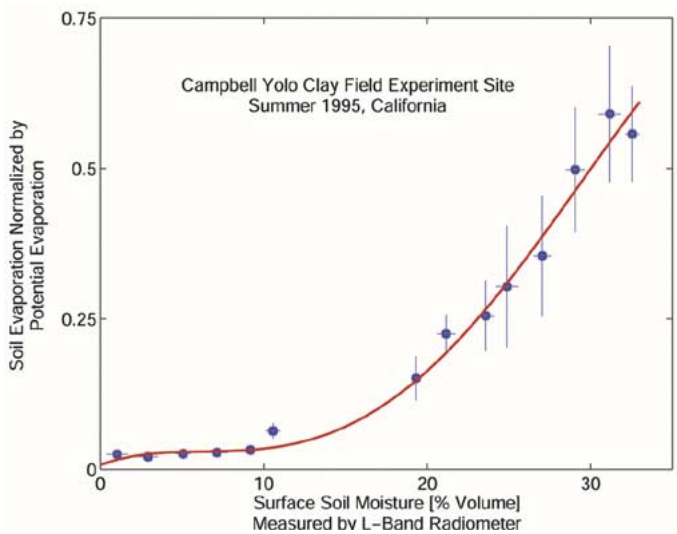

Fig. 2. Ground-based L-band radiometer is used to make the soil moisture field measurements to estimate the surface control on evaporation [5]. The red line is a fit through the discrete estimates. Global Hydros soil moisture measurements, together with meteorological and hydrological data, will allow for the first time a quantification of influential processes such as this across diverse climatic and seasonal regimes.

II. Science and Application Requirements for Soil Moisture and Land Freeze/Thaw Measurements

Measurements of soil moisture and its freeze/thaw state are critical components in approaching high-priority questions in earth system science today [1]. These include key questions about the water and energy cycle as well as the carbon cycle. Soil moisture is often the limiting factor in evaporation from the landscape. Plants transpire water by extracting moisture from the surface soil and throughout the root-zone. Evaporation from soil surface is also dependent on the availability of moisture. Since large amounts of energy are required to vaporize water, soil control on evaporation and transpiration also has a significant impact on the energy cycle. Soil moisture and its freeze/thaw state are also key determinants of the global carbon cycle. Carbon uptake and release in boreal landscapes is one of the major sources of uncertainty in assessing the carbon budget of the earth system (the so-called "missing carbon sink"). Hydros is an exploratory mission to demonstrate that global measurements of soil moisture and its freeze/thaw state can be made with the precision, spatial resolution, and temporal frequency to address critical science questions in water, energy, and carbon cycles.

A. Key Scientific Applications and Their Data Requirements

Global change projections on decadal and century time scales are built on foundations of conceptual understanding and modeling. However, there the significant uncertainty associated with the model-based projections is largely influenced by the uncertainty in the representation of land-surface processes. Whereas the uncertainty of different model projections of global change in terms of variables such as temperature may have lessened over the last few years, simulations of surface hydrological processes are at odds among climate models [2]. An effective way to diagnose errors in surface hydrologic processes in climate models is to examine how they simulate the partitioning of atmospheric forcing (available energy into sensible and latent heat flux and precipitation into runoff and infiltration) as a function of regional soil moisture [3], [4].

Fig. 2 shows the control of soil moisture over surface evaporation at a specific site [5]. The fractional surface evaporation (with respect to its upper limit, potential evaporation) is shown to depend strongly on surface soil moisture, here as measured by an L-band radiometer (a ground-based prototype of the Hydros instrument). The correct model representations of this relationship and the corresponding relationship for runoff ratio (ratio of runoff to precipitation) are critical for climate and global change studies. The relationship in Fig. 2 essentially represents the closure relationship that couples water and energy balance at the land surface. Land-surface models in atmospheric and hydrologic models require the specification of this closure relationship. However, the paucity of soil moisture data until now has restricted any substantial validation of this important closure relationship. Hydros measurements provide the required missing soil moisture element for performing such stringent tests of land-surface models.

V. Summary

This paper provides an overview of the Hydros mission including its science rationale and objectives. It also outlines the measurement approach and instrument requirements. The Hydros mission has been selected as a NASA ESSP pathfinder mission, and it is currently in the formulation phase, with a launch date in 2010. During the formulation phase, the Hydros mission design will undergo further studies to achieve the best design that meets the maximum science objectives with reduced technical and cost risks. The Hydros mission will be a core element of the NASA earth system science focus on the water, energy, and carbon cycles. It will also bring natural hazards applications such as severe weather forecasting, flash-flood prediction, and flood and drought monitoring capabilities into a new era.